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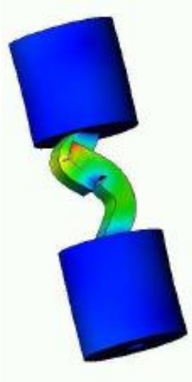

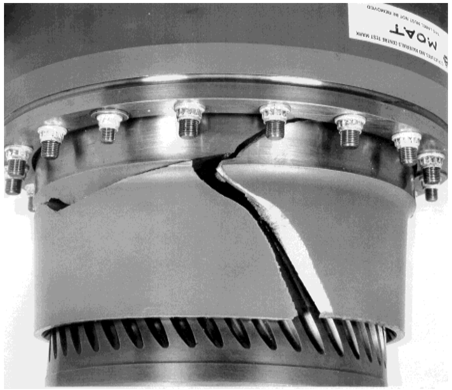

Project 1: Inverse Methods for Characterization of Contact Areas in Mechanical Systems

Kyle Starkey, Matthew Fronk, Kevin Eschen

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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SAND2017-7814 C

Introduction

- Students
  - Kyle Starkey (Purdue University)
  - Matthew Fronk (Georgia Tech)
  - Kevin Eschen (University of Minnesota)

- Mentors
  - Rob Kuether (SNL)
  - Adam Brink (SNL)
  - Tim Walsh (SNL)
  - Matt Brake (Rice University)
  - Wilkins Aquino (Duke University)

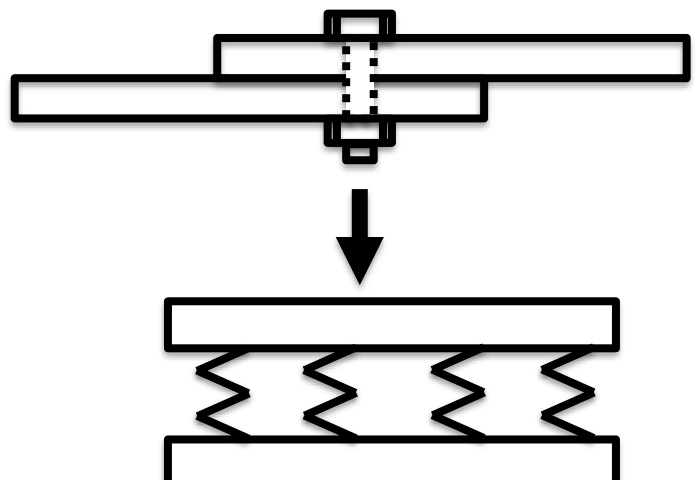
Motivation

Interface behavior can effect designs

Interfaces are difficult to measure and model

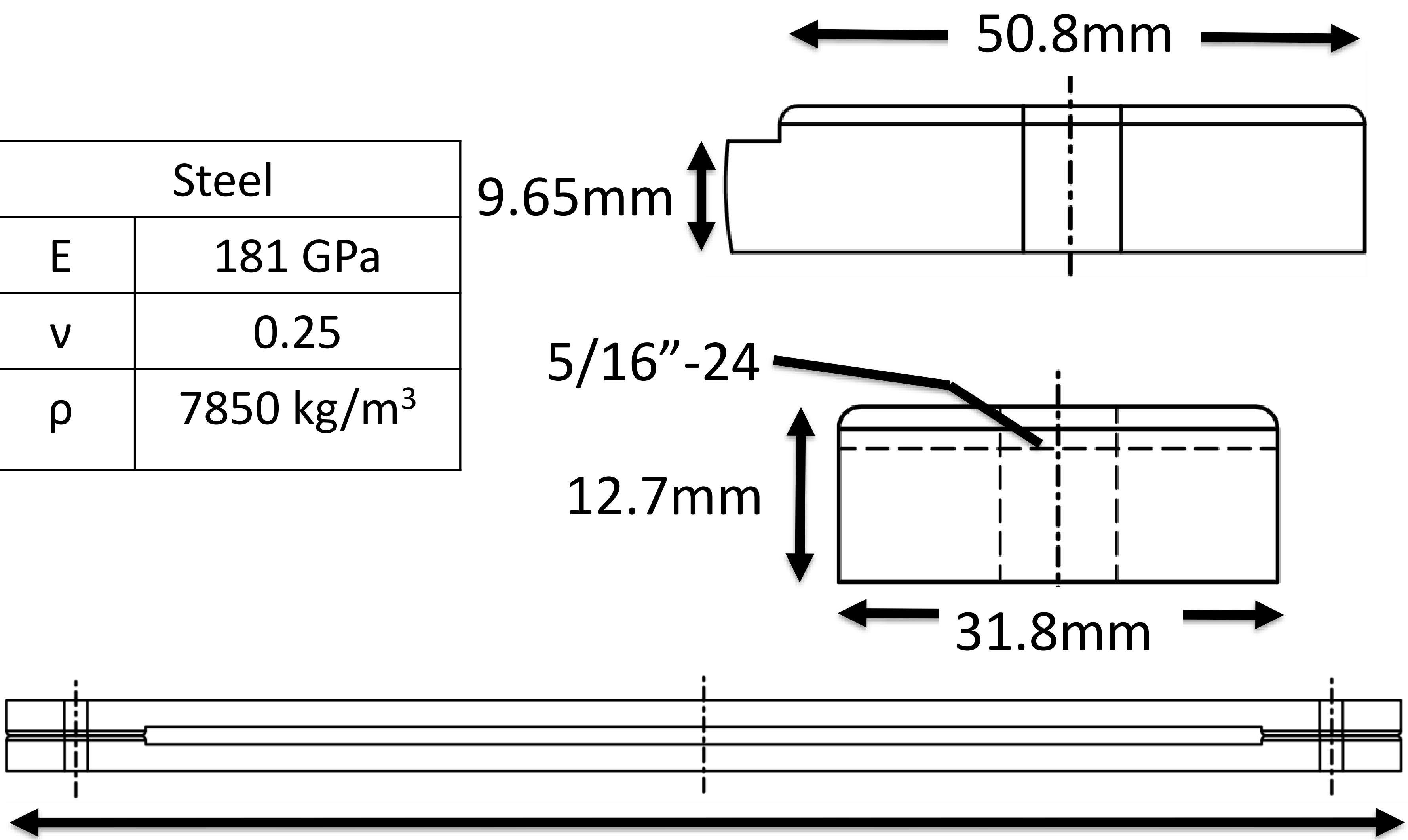
"The Mechanics of Jointed Structures", M. Brake

Simplifying assumptions overlook complex behavior



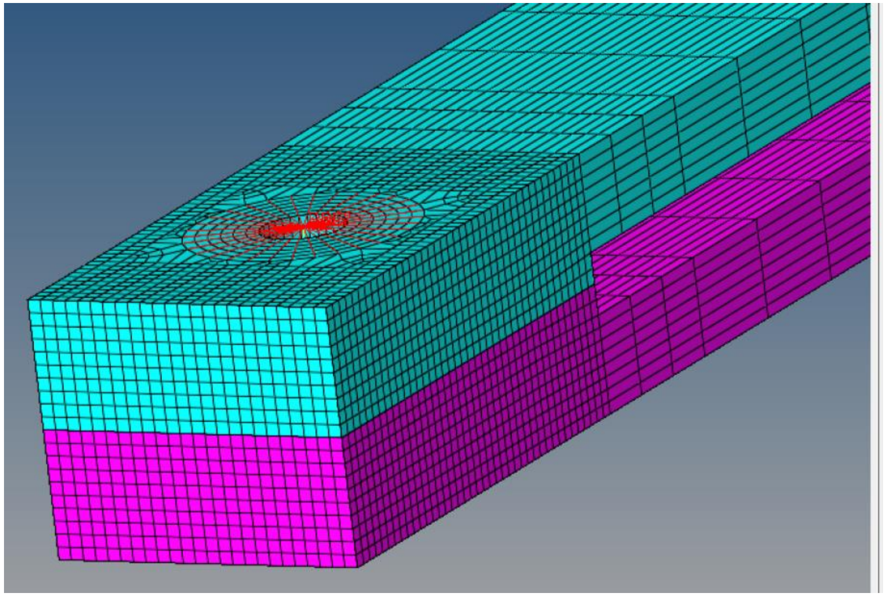
System

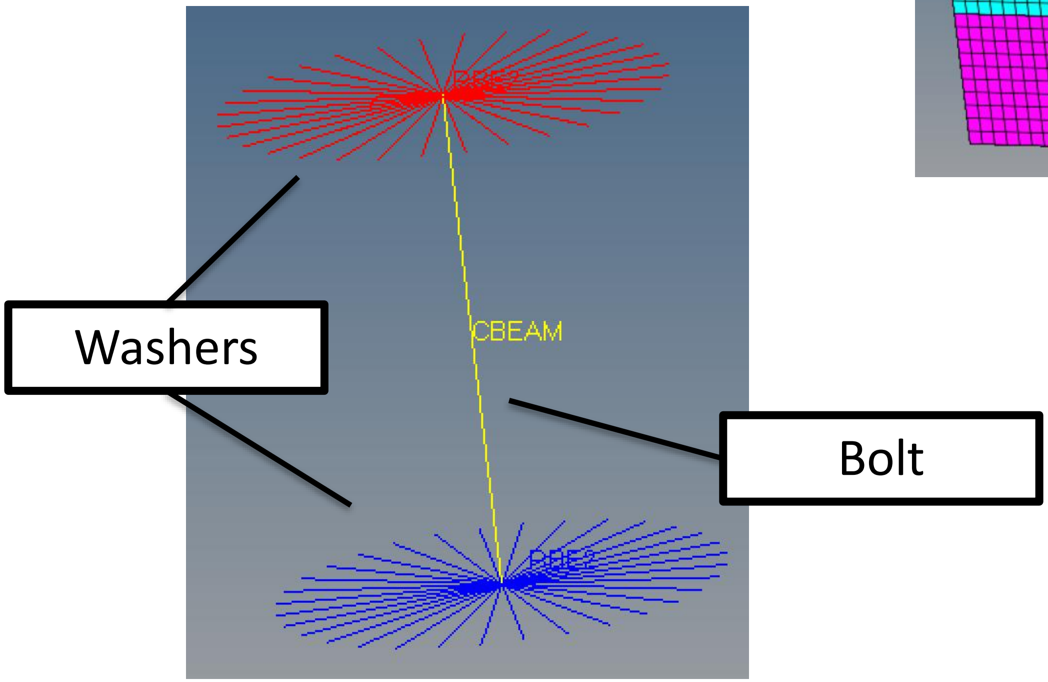
Steel	
E	181 GPa
ν	0.25
ρ	7850 kg/m³



Static Contact Patch Analysis

- Bolt pretension
- Inertial relief
- Static friction ($\mu = 0.3$)
- NL quasi-static solver
- Contact pressure

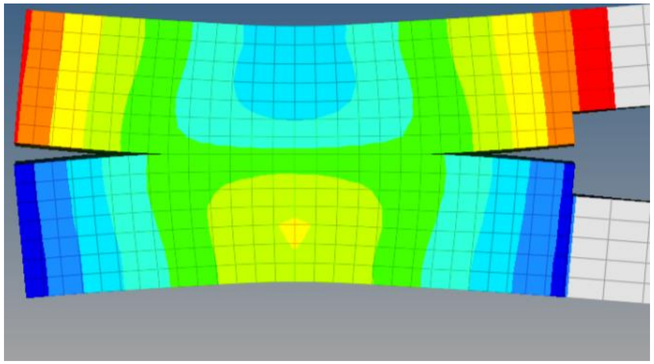


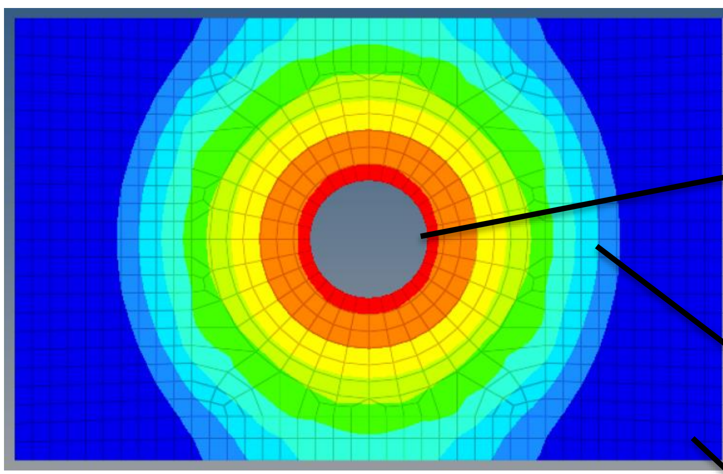


Torque (N-m)	Motosh Eqn Force (N)	Lacayo et al Force (N)
2.4	1685	1020
6.1	4276	2590
9.3	6479	3925

Static Contact Patch Analysis: Results

FEA



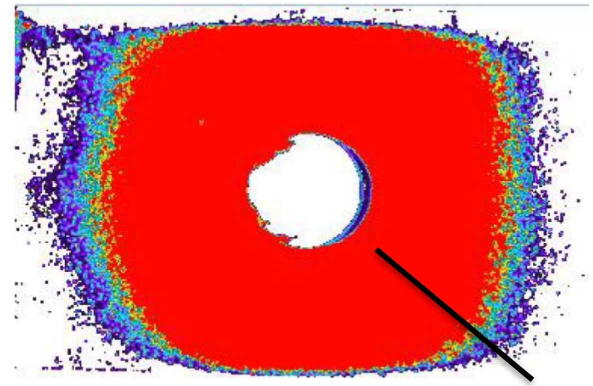


11 MPa

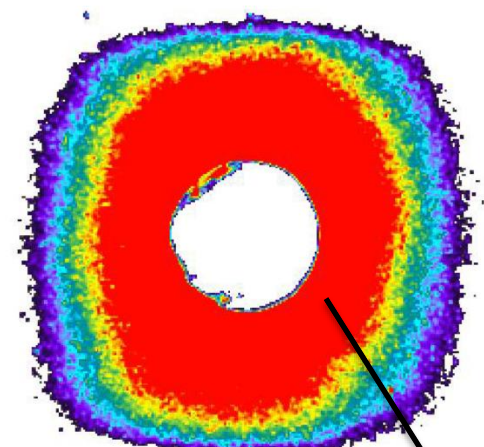
3.8 MPa

0 MPa

Pressure films

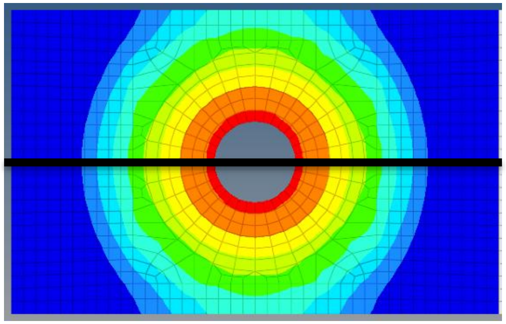


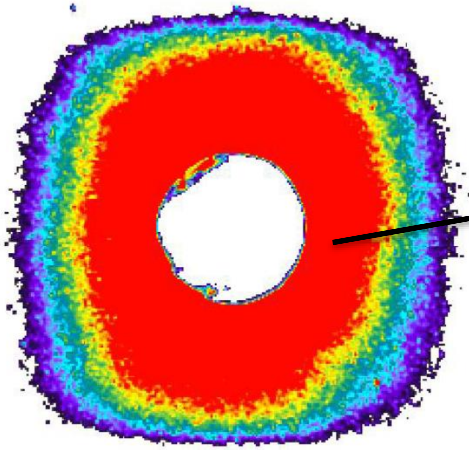
9.7 MPa

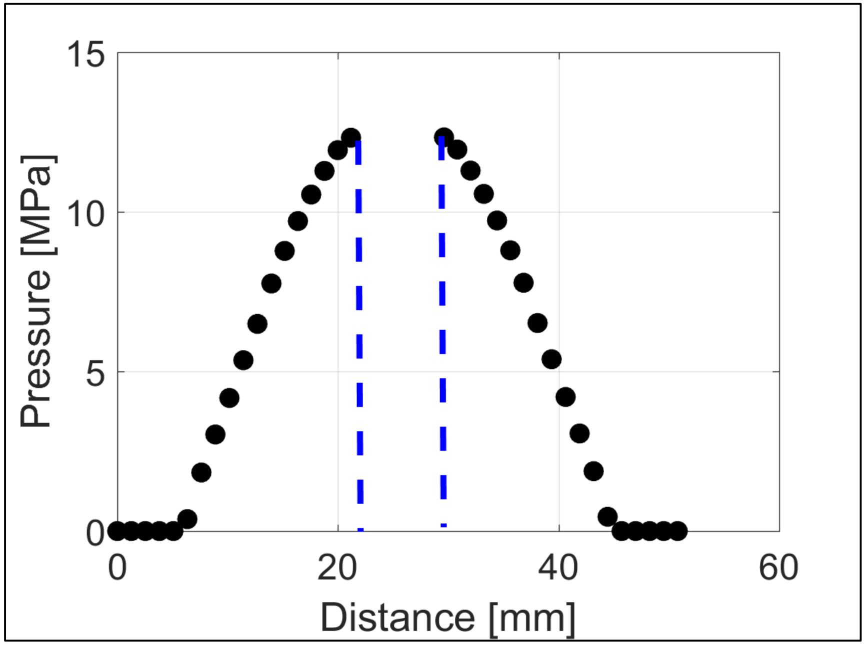


49 MPa

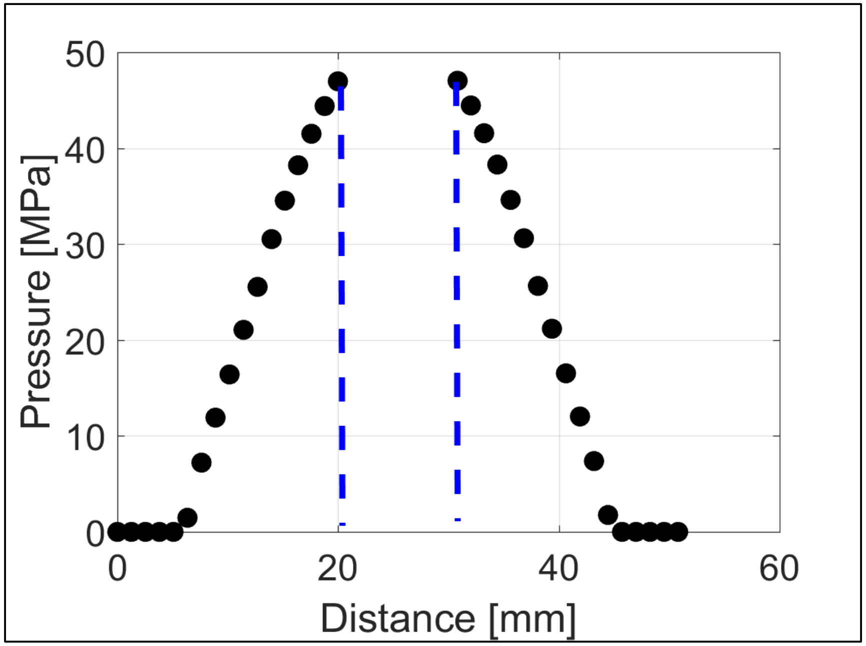
Load Calibration





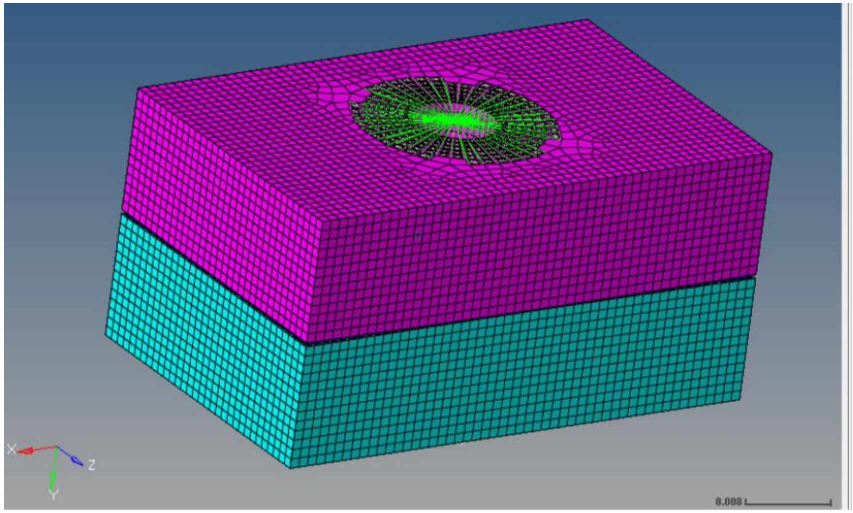


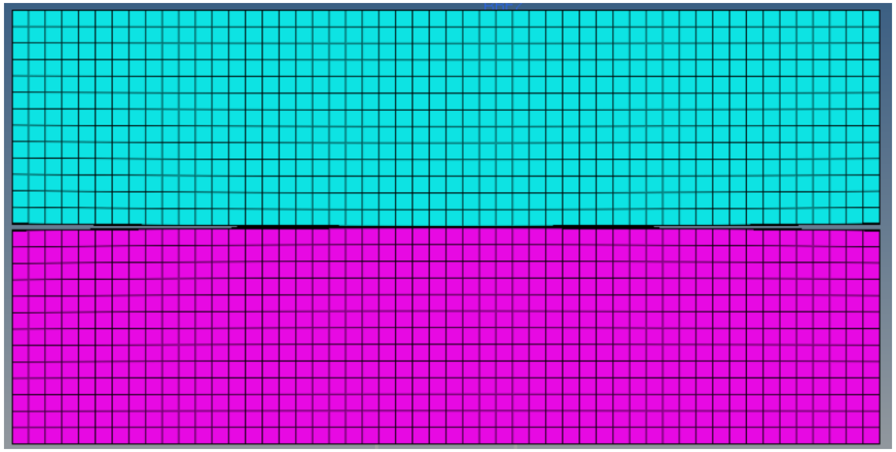
$F_{preload} = 6479\ N$ (Motosh)

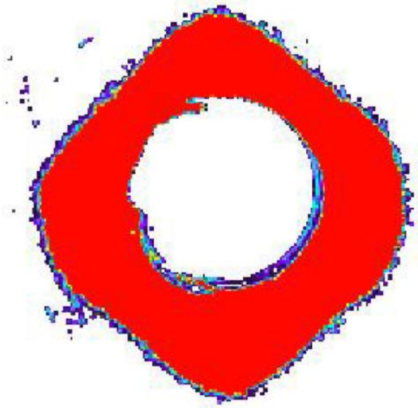


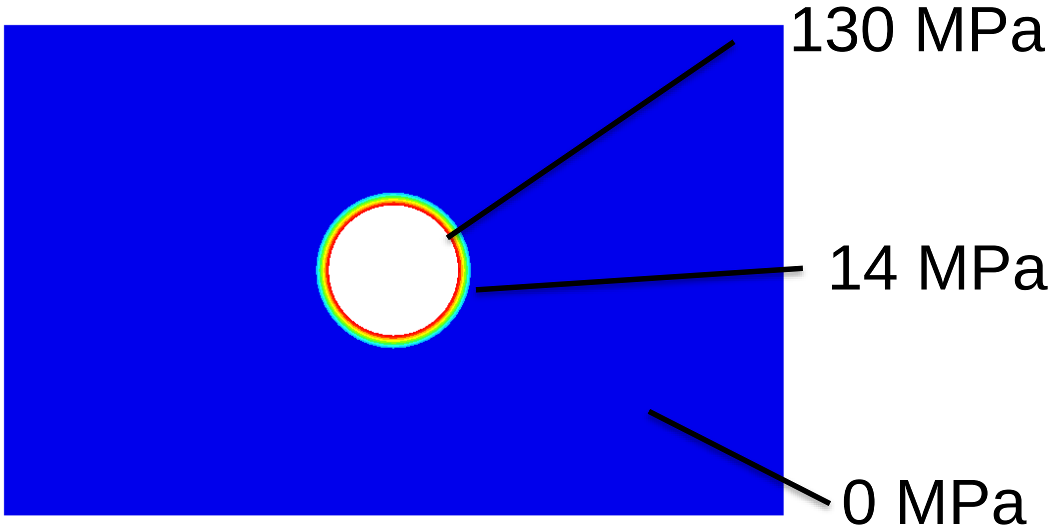
$F_{preload} = 25500\ N$ (Calibrated)

Rounded Interface





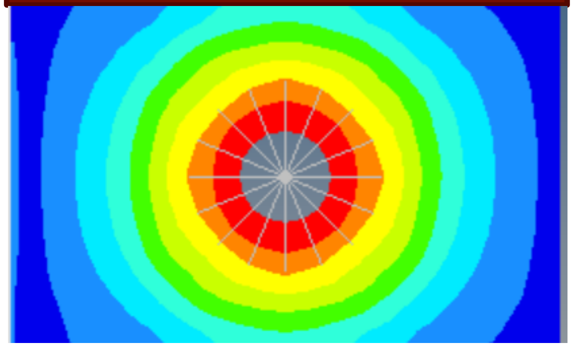




SPIC - Definition

Single **P**arameter **I**nverse **C**ontact

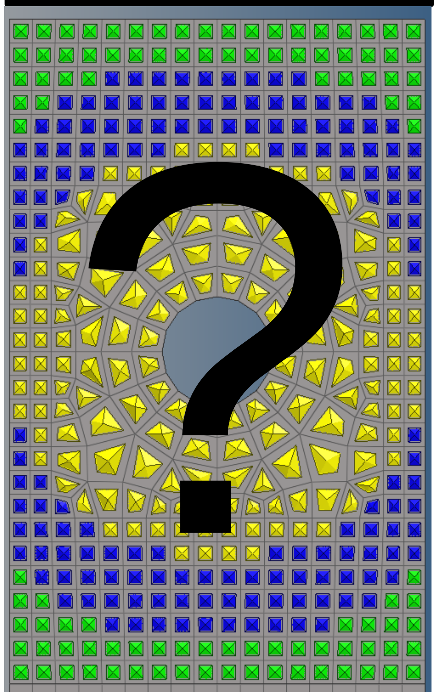
Static Pressure Analysis



System Parameters

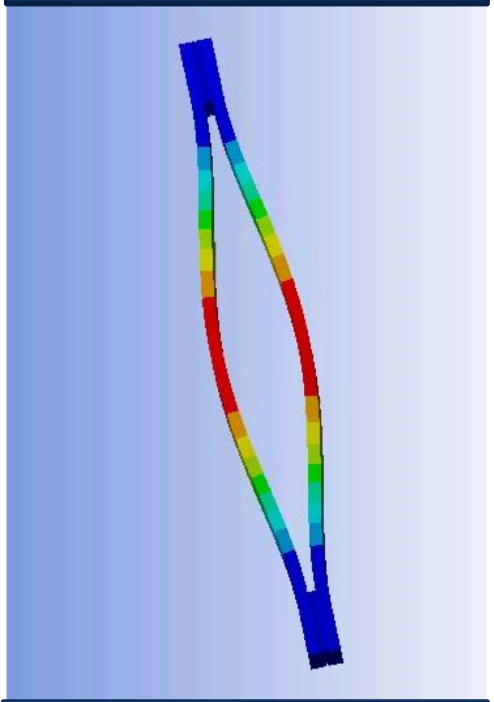
- Geometry
- E, ν, ρ
- F_{app}

Contact Definition



- Fully Stuck
- Sliding
- No Contact

Modal Frequencies



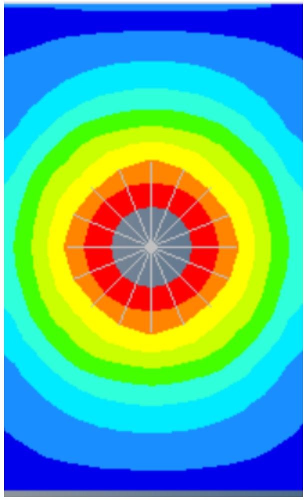
For multiple elastic modes

Input

System

Output

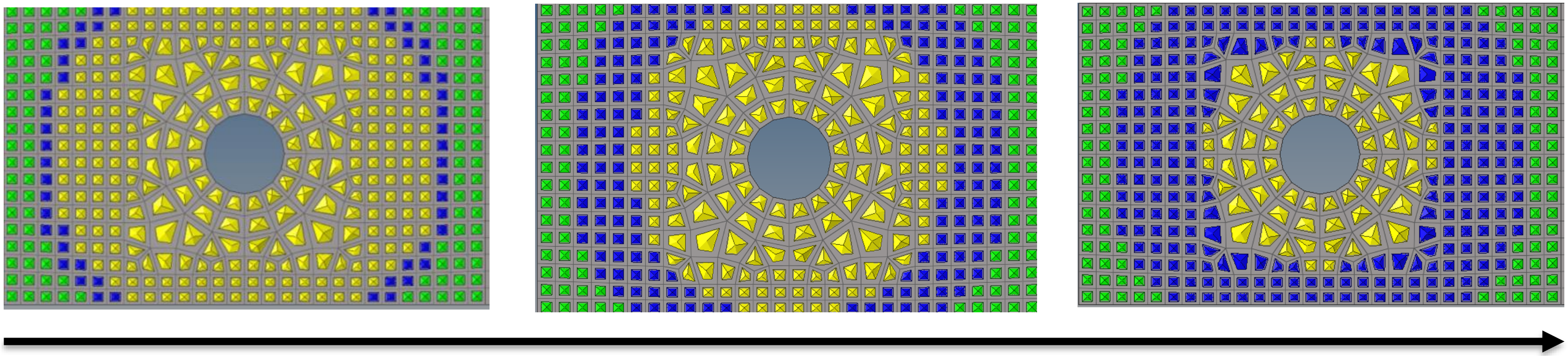
SPIC – Definition 1



$$0 \geq p_{element} \rightarrow \text{No Contact}$$

$$0 < p_{element} < p_l \rightarrow \text{Sliding Contact}$$

$$p_{element} \geq p_l \rightarrow \text{Stuck Contact}$$

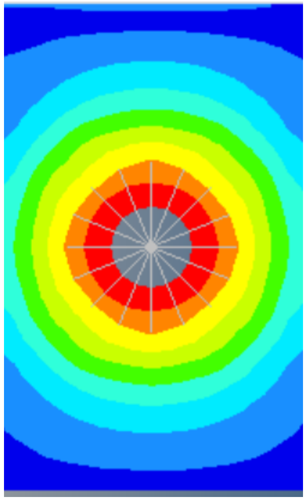


Mostly Stuck

p_l increasing

Mostly Sliding

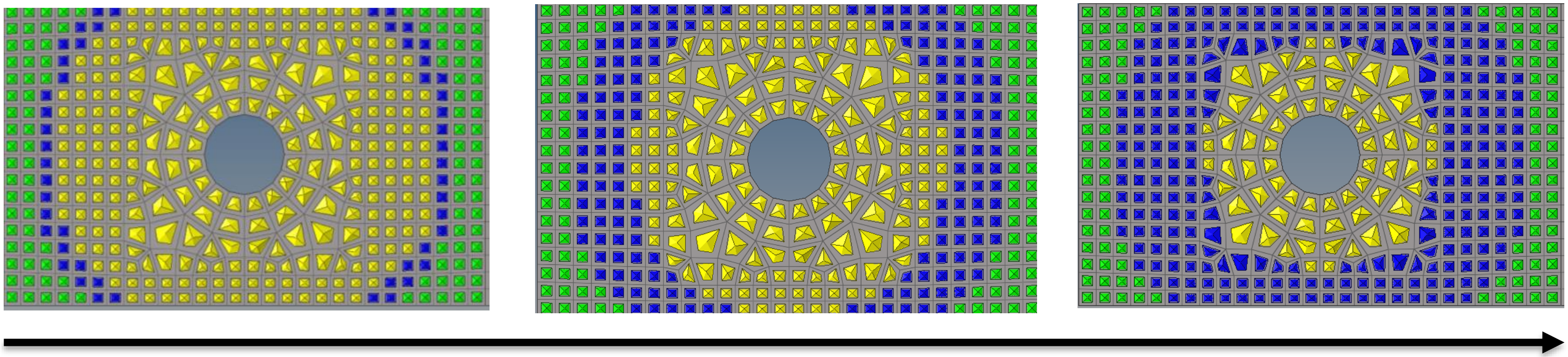
SPIC – Definition 2



$0 \geq p_{element} \rightarrow$ No Contact

$0 < p_{element} < p_l \rightarrow$ No Contact

$p_{element} \geq p_l \rightarrow$ Stuck Contact



Mostly Stuck $\qquad$ p_l increasing $\qquad$ Mostly No Contact

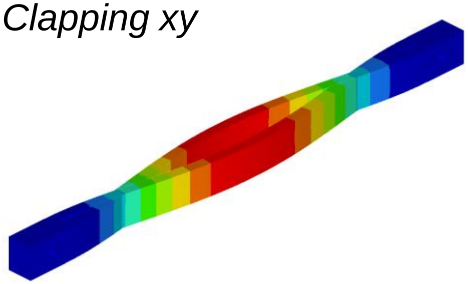
SPIC - Goal

Find p_l at which the numerical simulation matches the experimental modal frequencies

SPIC - Modes

Mode 7

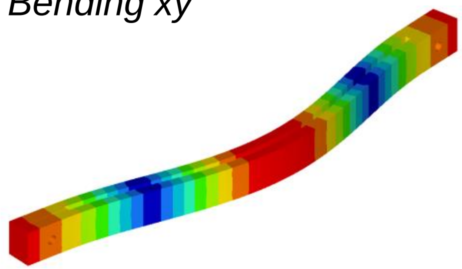
1st Clapping xy



$f_{n7,exp} = 258.0\ Hz$

Mode 8

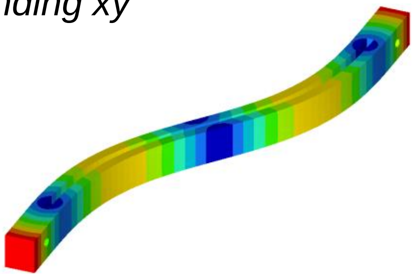
1st Bending xy



$f_{n8,exp} = 331.7\ Hz$

Mode 9

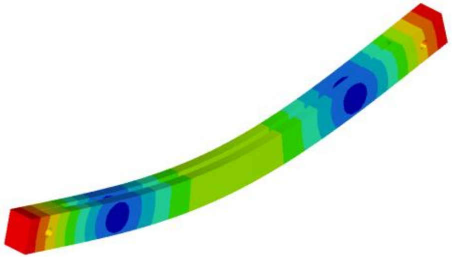
2nd Bending xy



$f_{n9,exp} = 478.6\ Hz$

Mode 10

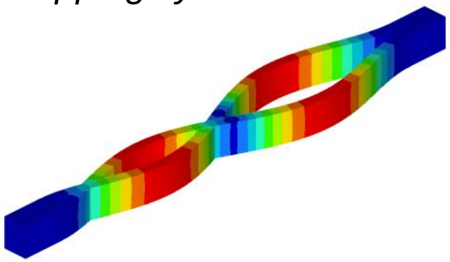
1st Bending xz



$f_{n10,exp} = 567.6\ Hz$

Mode 11

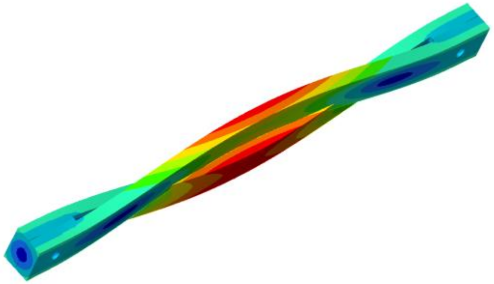
2nd Clapping xy



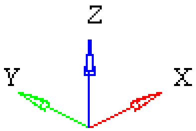
$f_{n11,exp} = 708.2\ Hz$

Mode 12

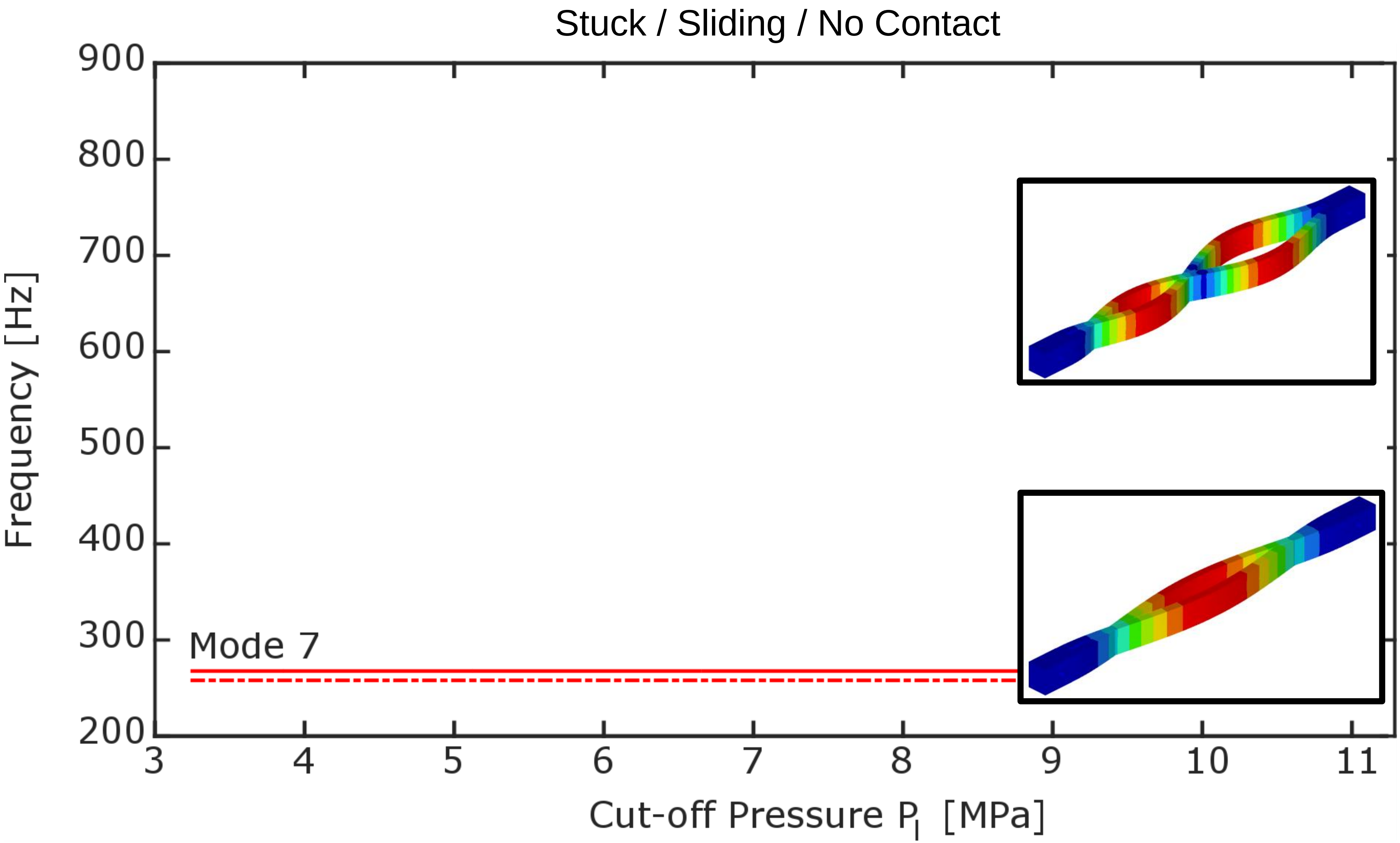
1st Clapping xz



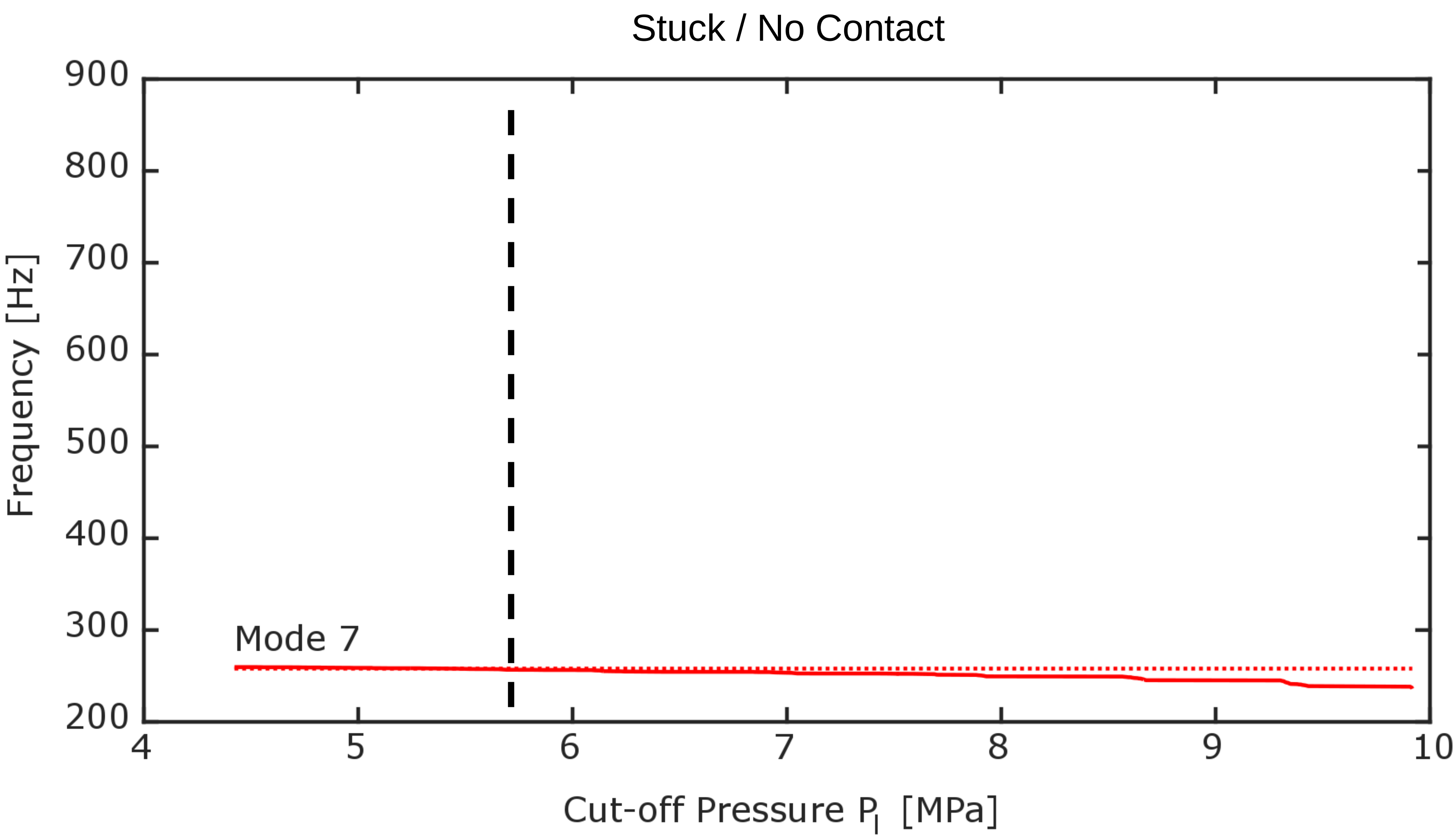
$f_{n12,exp} = 849.5\ Hz$



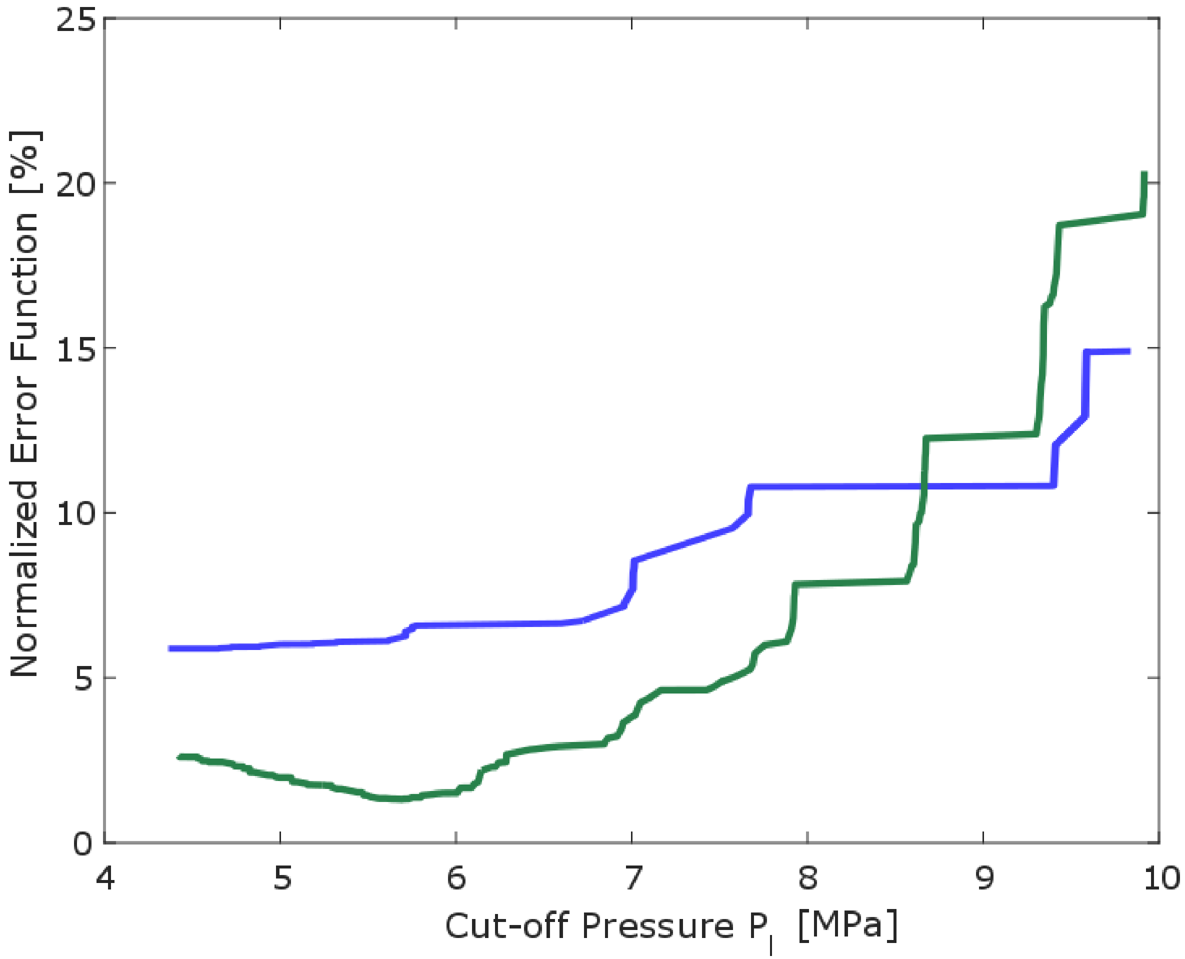
SPIC– Results 1

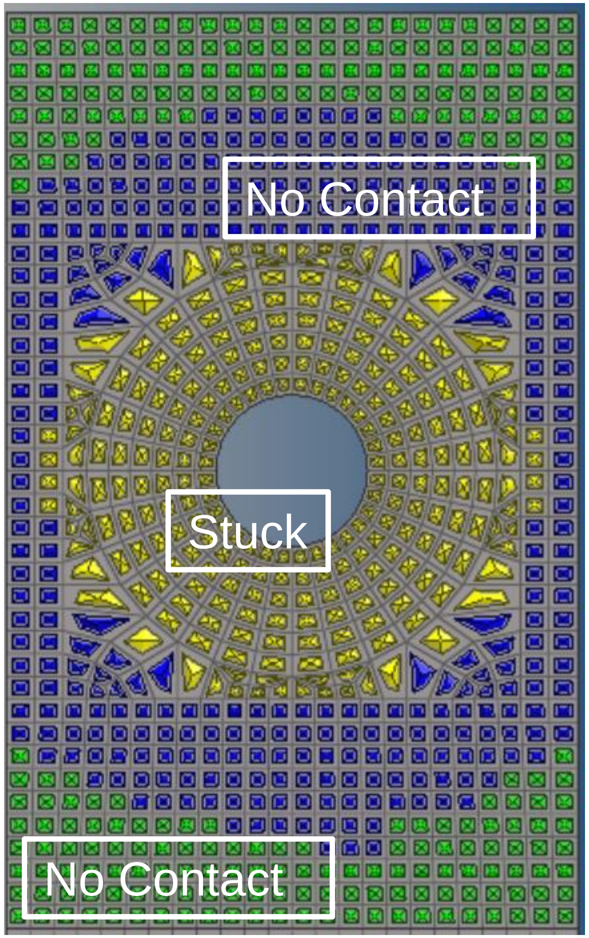


SPIC– Results 2



SPIC - Results





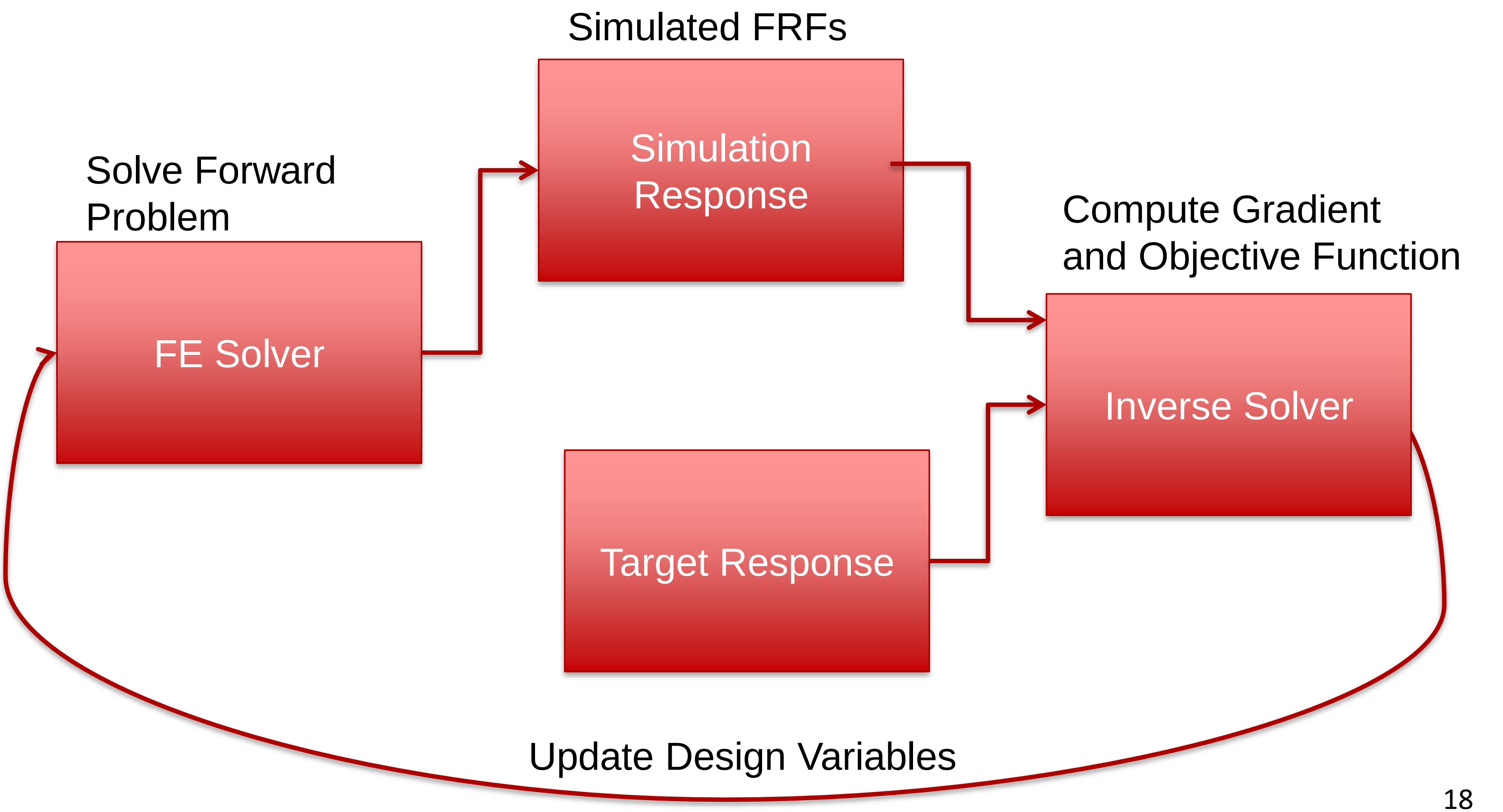
Stuck / Sliding / No Contact

Stuck / No Contact

Contact Area Inversion

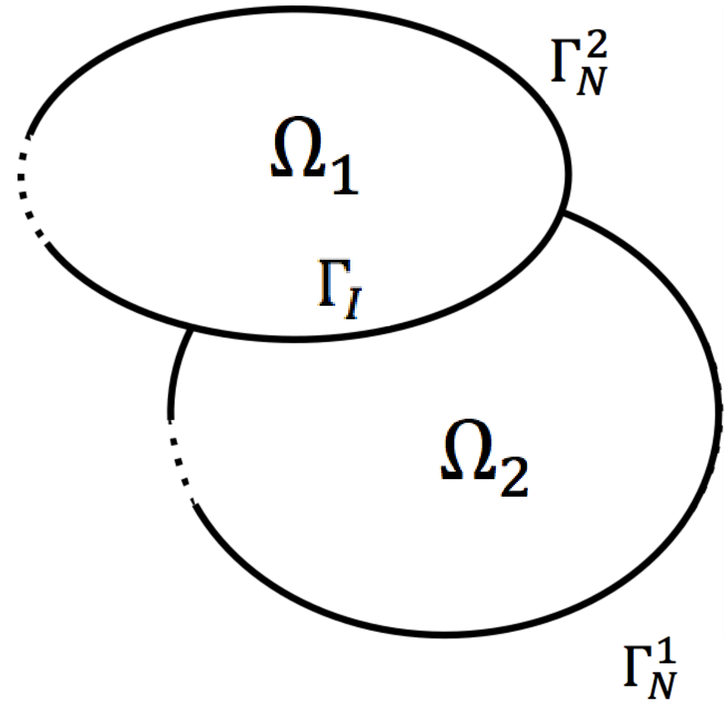
- Objective: determine contact area from global measurements of displacements
  - We may or may not have a-priori knowledge of contact area, whereas SPIC has knowledge of the static patch.
  - We will represent the contact patch as a density field and enforce contact with a penalty parameter
  - We will only consider stuck contact. So as of now, no friction or sliding contact will be addressed

Inverse Problems Flow Diagram



Forward Problem

$$\nabla \sigma^i + \rho^i \omega^2 u^i = 0 \text{ in } \Omega_i$$
$$\sigma^i n^i = \tau^i \text{ on } \Gamma_N^i$$
$$\sigma^I n^I + \alpha(u^1 - u^2) = 0 \text{ on } \Gamma_I$$
$$\sigma^i = C^i : \epsilon_u^i$$
$$\epsilon_u^i = \frac{1}{2}\left(\nabla u^i + \left(\nabla u^i\right)^T\right)$$



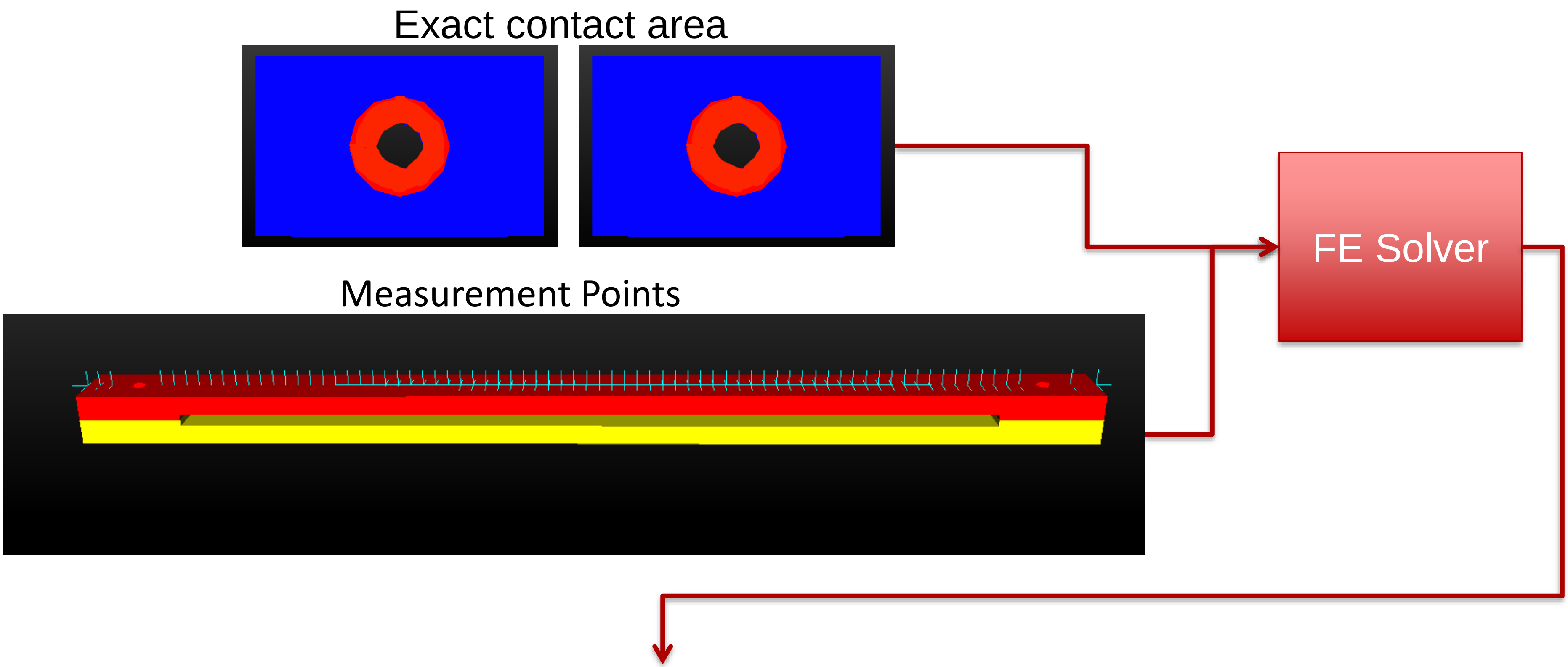
Where α is the penalty parameter.
Since we do not know Γ_I beforehand, we will represent it with a density field p.

Inverse Problem Statement

minimize $|(u - u_m)|^2$
where $u = [u_1, u_2]^T$
subject to:

$$\begin{bmatrix} K_1 - \omega^2 M_1 + \alpha Q_{11}(p) & -\alpha Q_{12}(p) \\ -\alpha Q_{12}(p) & K_2 - \omega^2 M_2 + \alpha Q_{22}(p) \end{bmatrix} \begin{bmatrix} u_1 \\ u_2 \end{bmatrix} = \begin{bmatrix} F_1 \\ F_2 \end{bmatrix}$$

Problem Set-up For Numerical Experiment



Measured displacement data for the inverse problem!

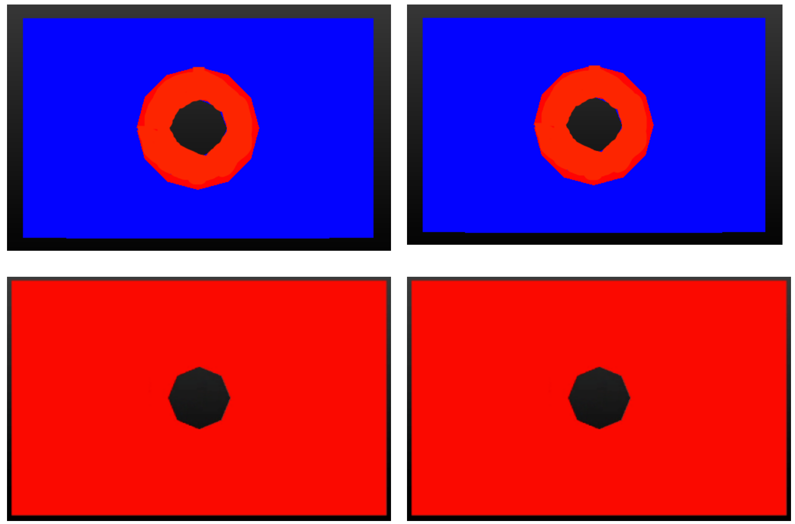
This is the only knowledge we provide to the inverse method,
so we assume no a-priori knowledge of the contact patch profile.

Contact Patch Results

Left interface Right interface

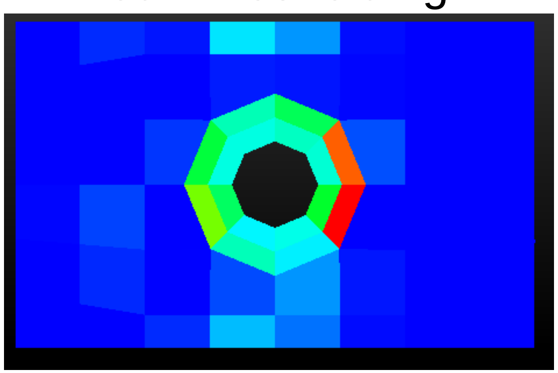
Exact contact area from numerical experiment.

Initial guess: contact everywhere

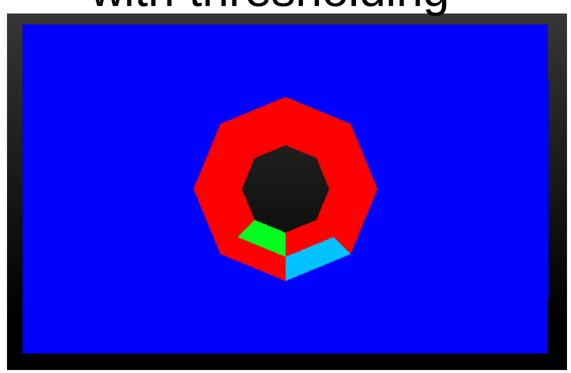


Red: in contact
Blue: no contact
all other colors are in between

Left interface
without thresholding



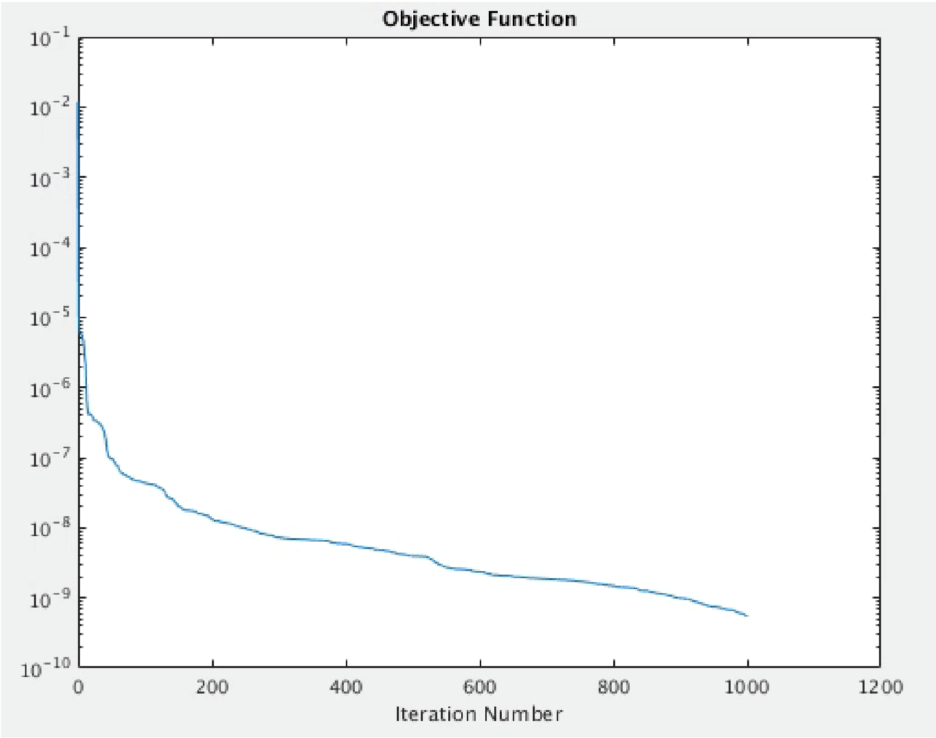
with thresholding

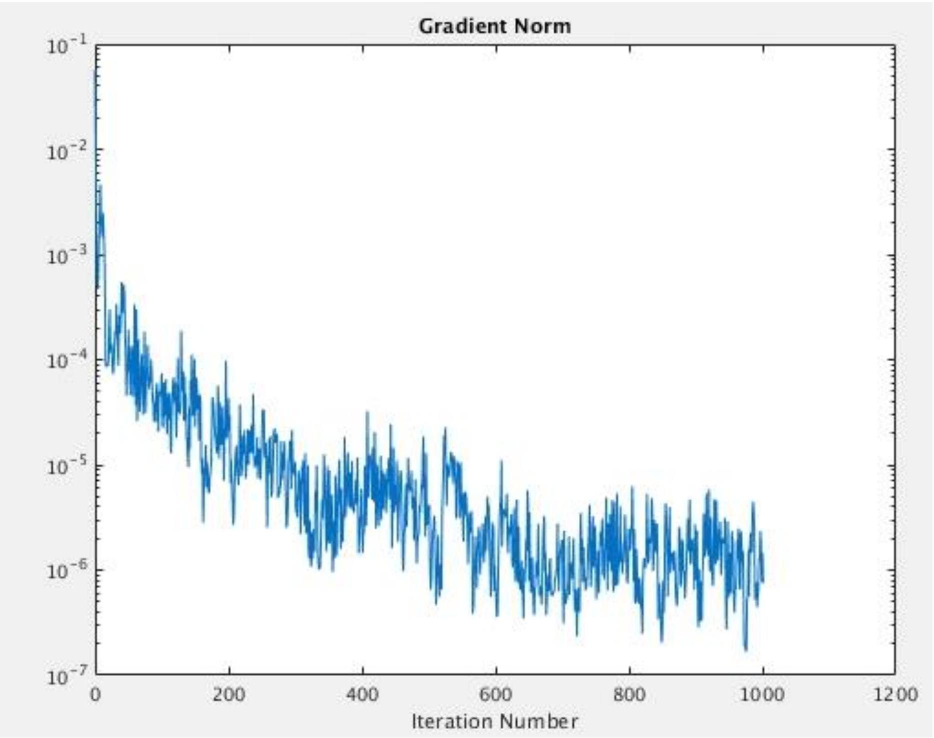


Inverse results: generally finds correct region of contact/no contact

Contact Patch Results

Convergence of objective function and gradient during optimization





Summary and future work

- Preliminary work started with simulated data to understand the problem
- With simulated data, we demonstrated we can obtain reasonable reconstructions of contact area
- It is important to identify the frequencies where there is sensitivity to solution
- Work with experimental data
- Continue to improve formulation by adding a friction model
- Improve numerical performance by adding exact hessian information rather than just using a rank two updates with bfgs.

Conclusions

- Static contact patch shapes remain constant for a flat-on-flat interface and can be calibrated to match values of pressure film measurements
- Single parameter inverse contact modeling based on static pressure patches gives physical insight into the contact characteristics of jointed systems

Acknowledgments

- This research was conducted at the 2017 Nonlinear Mechanics and Dynamics Research Institute supported by Sandia National Laboratories.

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